Solid Oxide Fuel Cell Hybrid System for Distributed Power Generation

Quarterly Technical Progress Report
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Abstract

This report summarizes the work performed by Honeywell during the July 2002 to September 2002 reporting period under Cooperative Agreement DE-FC26-01NT40779 for the U. S. Department of Energy, National Energy Technology Laboratory (DOE/NETL) entitled "Solid Oxide Fuel Cell Hybrid System for Distributed Power Generation". The main objective of this project is to develop and demonstrate the feasibility of a highly efficient hybrid system integrating a planar Solid Oxide Fuel Cell (SOFC) and a turbogenerator.

For this reporting period the following activities have been carried out:

- Conceptual system design trade studies were performed
- System heat exchanger requirements were developed
- Dynamic control model has been modified to reflect current system concepts
- Preliminary heat exchanger designs were refined
- One hundred percent increase in cell performance at 3 atms was demonstrated

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Executive Summary

This report summarizes the work performed by Honeywell during the July 2002 to September 2002 reporting period under Cooperative Agreement DE-FC26-01NT40779 for the U. S. Department of Energy, National Energy Technology Laboratory (DOE/NETL) entitled "Solid Oxide Fuel Cell Hybrid System for Distributed Power Generation". The main objective of this project is to develop and demonstrate the feasibility of a highly efficient hybrid system integrating a planar Solid Oxide Fuel Cell (SOFC) and a turbogenerator.

The hybrid system is based on Honeywell planar SOFC and turbogenerator power technologies. The planar SOFC is based on thin-electrolyte cells and metallic foil interconnects. This technology leads to SOFC stacks that operate at reduced temperature (<800°C) and have reduced materials cost. This work will culminate in testing of a small SOFC-based hybrid system that will incorporate all of the components/subsystems required for a full-fledged system.

The work consists of three phases and will focus on defining and optimizing a suitable system concept, conducting experiments to resolve identified technical barriers, performing cost analysis, and testing a small hybrid system to demonstrate concept feasibility.

The various phases and tasks to be performed under this program are attached. For this reporting period the following activities have been carried out:

- Conceptual system design trade studies were performed
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Approach and Results

1. <u>TASK 1A.1 – SYSTEM DESIGN</u>

1.1 SUBTASK 1A.1.1 – DESIGN CONCEPT DEVELOPMENT.

The previous quarterly report documented the system conceptual design studies and the concept down selection process. The down selected concept with the most promising system efficiency potential is shown on Figure v2-1. This concept was further studied, and component problem requirements and issues were analyzed in the reported period.

The design concept was further refined by the addition of a start-up combustor and valves and devising the conceptual start-up and power ramp-up procedures. The primary additions to the conceptual design are the start-up air and fuel valves and the fuel cell check-valve. All these components were introduced to facilitate the start-up procedure.

1.1.1 Conceptual System Design Trade Studies

Some component trade-offs were added to the conceptual system design. The most important trade-off concerns the high temperature rise across the fuel cell stack assumed in the conceptual trade studies. The 200°C temperature rise may introduce a significant risk of stack failure due to high thermal stress in the stack. The temperature rise is controlled by the airflow through the cathode side of the stack. In addition to cooling, the airflow provides oxygen required for the fuel cell reaction. The airflow is chosen in relation to the fuel cell power so that the stack temperature rise requirement is met. The resulting oxygen utilization is quite low even at the flow rate corresponding to the 200°C temperature rise. Further increasing the flow rate in order to lower the temperature rise and improve the stack reliability will lower the oxygen utilization and therefore, lower the system efficiency as well. Some alternative ways of lowering the temperature rise while minimizing the efficiency hit were sought during the reported period. Further discussion is provided in Volume 2

Each system configuration will be analyzed to determine the component requirements. Components will then be selected, and the system parameters calculated based on the component information. The system parameters will be used to calculate the cost of electricity.

1.1.2 Conceptual System Component Design

During the reporting period, the system design presented on Figure 1 was analyzed using the approach outline above. Based on the initial conceptual analysis, performance requirements for the system components were created and distributed for size, performance and cost estimations. The performance requirements were created using the system heat and material balances derived during the conceptual analyses. At the time of the report, the designs of the heat exchangers were completed. The design and selection of other system components are still underway at this time.

1.1.2.1 Heat Exchangers

There are five heat exchangers present in the system, namely the recuperator, the air preheater, the reformate gas preheater, the natural gas heater, and the steam generator.

The performance requirements for the NG heater, the steam generator, and the reformate preheater are presented in Table v2-1 through 3 respectively. These units were designed in the High-Temperature Heat Exchanger Task and will be described later in the document.

It is assumed that the Parallon 75 recuperator will be used in the hybrid system. Its performance characteristics were used without modifications in the hybrid system design. The recuperator has a 1200°F temperature limit, which limits the turbine inlet temperature to about 1700°F as well as the cathode air inlet temperature. This temperature limit necessitates the use of an additional heat exchanger, the air preheater.

The air preheater performance requirements are shown in Table v2-4. While the effectiveness requirements are not difficult to meet, the high hot side inlet temperature requirements make material selection a difficult task. Most of the metal candidates identified in the High-Temperature Heat Exchanger Task have very low yield strength in the temperature range above 1800°F and therefore, the air preheater is likely to have a low reliability.

It should be noted that the system designs shown on Figure 2 and 4 eliminate the need for the air preheater. Further discussion in Volume 2.

1.2 CONTROL SYSTEM

1.2.1 System Control Approach

The control system will provide the operator with the ability to automatically step through the startup sequence, regulate to commanded load demand points, step down through the normal shutdown sequence, perform basic health monitoring of the system, and handle emergency shutdown of the system. A dynamic model of the system has been developed using GE Hybrid Power Generation System's proprietary library of fuel cell system component models, and will be used to design and evaluate various control strategies prior to hardware implementation. The design of efficient controls for the fuel cell system requires consideration of many factors, significantly:

- With potentially wide load fluctuations, the controller should be able to maximize efficiency in different operational regions. These include conditions that occur during startup, steady state operation and shutdown.
- The controller should be able to regulate power and voltage during steady state operation and maximize efficiency at setpoint.
- The controller should be able to minimize thermal stress and fatigue and limit component duty cycles that adversely affect the lifetime of the equipment.

In addition to the basic control functions, the controller will provide built-in test (BIT) and health monitoring around the system. The BIT will monitor sensors throughout the system and trigger alarms to shutdown the system if a sensor exceeds the specified operating range. Corrective and protective action will be programmed into the BIT to handle various failure modes or unscheduled events.

Figure v1-1 shows the design for control process that is being used for control system development. The controls task is currently in the Controls Requirements Definition process block. During this stage of the process subsystem and system models are being developed and analyzed, the control loop analysis is being conducted to determine the dominant dynamic interactions in the system, and preliminary controls requirements are being formalized. The third quarter of 2002 has been primarily focused on building the dynamic system model and negotiating with other task teams on requirements for the system and various subsystems.

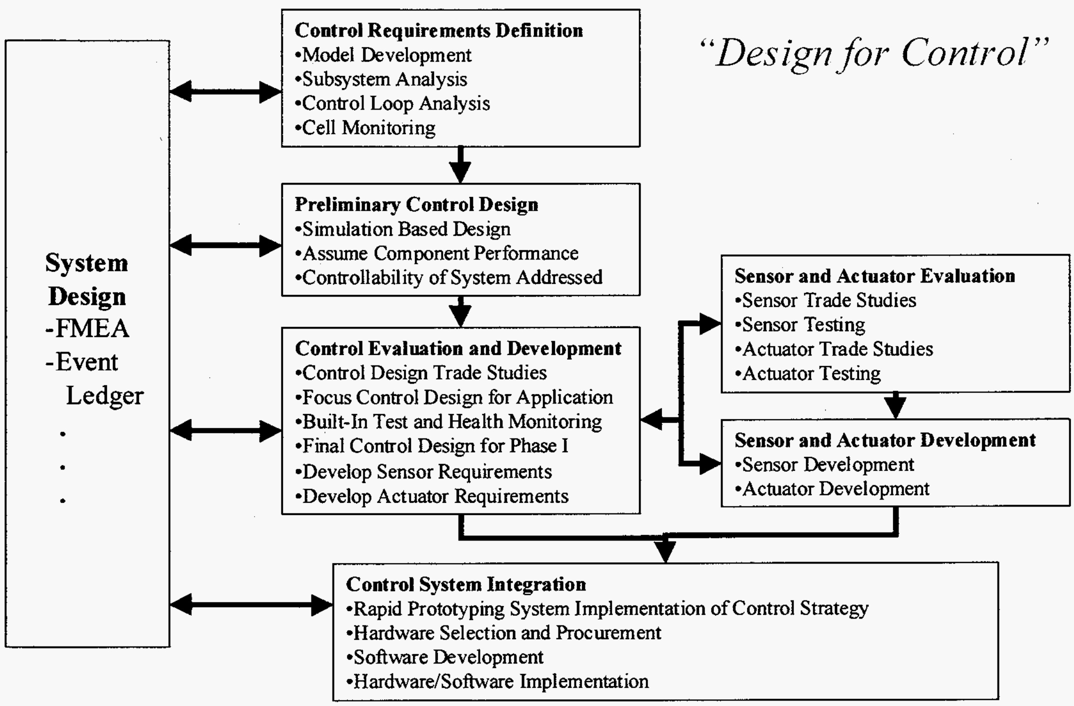

Figure v2-1: Controls Design Process

1.2.2 Control System Development

A dynamic system model of the conceptual system has been assembled using GE Hybrid Power Generation Systems' (HPGS) proprietary Fuel Cell Dynamic Component Library (Figure v2-5). This model will be used to determine significant dynamic interactions within the system, perform various component and system level trade studies, and to develop the control system design. The model will be updated to allow dynamic issues to be addressed as the system design changes and matures. This approach minimizes costs by reducing hardware tests and the risk of damaging components.

With the introduction of new system concepts and the system level performance trade studies that were enabled through consideration of a sealed SOFC, it became necessary to update the dynamic system model. A sealed stack and independent combustor model were therefore added to the dynamic system model to investigate the dynamic implications of anode and cathode recycle. With the ongoing system level trade studies, the current focus for dynamic analysis and control design revolves around the chemical subsystem which includes the steam reformer, SOFC, combustor, and recycle blowers. The chemical subsystem has been a major focus of modeling efforts during Q3 and will continue to be a focus on Q4 since this subsystem is common to all four systems currently being studied. A dynamic model of the chemical subsystem (Figure v2-6) has been assembled and is currently being analyzed.

Work has continued during Q3 in the area of feedback controls development (Section v2 1.2.2.1). Work has begun on the supervisory controls in the following areas:

- Key independent variables
- Key System Constraints
- System Start-up
- System Operating Modes and Transitions

The supervisory controls are discussed in more detail in Section v2 1.2.2.2.

2. TASK 1A.2 – TECHNICAL BARRIER RESOLUTION

2.1 SUBTASK 1A.2.1 – HIGH-TEMPERATURE HEAT EXCHANGERS.

The conceptual system design (Figure v2-1) requires four heat exchangers that operate at high temperatures. Preliminary designs of these heat exchangers are presented in Table v2-6. The requirements on these heat exchangers included high effectiveness and compactness that will result in low-cost designs. The pressure drops in the heat exchanger flows were kept to the minimum possible to reduce the parasitic power losses, and consequently increase the system efficiency.

2.2 SUBTASK 1A.2.2 – PRESSURIZED SOFC

2.2.1 Endurance Test

In the last reporting period, an endurance test of more than 850 hours under pressure was conducted. In order to understand the performance degradation, impedance analysis was used to characterize the cell resistance. The analysis results revealed significant ohmic resistance increase after the cell has been tested for more than 850 hours at 800°C. The cell ohmic resistance was about 0.85 ohm-cm^2 after test compared to 0.14 ohm-cm^2, which was typically observed in a fresh cell. The ohmic resistance increase over 850 hours is much higher than that predicted from metal oxidation data in air at ambient pressure.

To understand the degradation mechanism, two approaches are being taken. Efforts in these two areas are initiated and results will be collected and reported later.

2.2.2 Performance Improvement

In order to close the gap between the target and current cell performance, cell microstructures are being modified. Excellent cell performance was demonstrated with improved cathode and anode microstructures.

The advanced cell integrates the improved cathode and anode microstructures, leading to significant performance increase at high fuel utilization. Table v1-5 summarizes the performance at ~0.7V and 75% fuel utilization comparing the advanced cell (RJ025) to a baseline cell (RJ012). All the tests were conducted at 800°C with 64%H_2 balance N_2 as fuel under pressures of 1, 2, and 3 atm. The advanced cell doubled performance at 75% fuel utilization compared to a "baseline" cell tested earlier under this program. With baseline cell microstructure, the cell voltage couldn't sustain at 75% fuel utilization, however, 0.235 W/cm^2 was obtained at cell voltage of 0.687V with the advanced cell. At cell voltage about 0.7 V, 115% and 104% performance increase over the baseline cell was demonstrated with the advanced cell microstructure at pressure of 2 and 3 atm, respectively.

Table v1-5 Cell performance improvement with advanced cell microstructure

		Improved Cell RJ025		"Baseline" RJ012		
Fuel Util., %	**Pressure, atm**	**Cell V, V**	**PD, W/cm2**	**Cell V, V**	**PD, W/cm2**	**PD increase, %**
75%	1	**0.687**	**0.235**	unstable		
75%	2	**0.688**	**0.394**	0.636	0.183	115%
75%	3	**0.701**	**0.402**	0.685	0.197	104%

2.2.3 Scale-up

Design for additional pressurized SOFC test stands to accommodate larger cells and higher pressure (4 atm) has been completed. Pressure vessel and other critical test stand parts have been ordered. Stand assembly and verification will be started as soon as all the parts are available

Summary

- Conceptual system design trade studies were performed and the variations on the primary concept were developed and studied
- System heat exchanger requirements were developed
- Dynamic control model has been modified to reflect current system concepts
- Preliminary heat exchanger designs were refined
- One hundred percent increase in cell performance at 3 atmospheres was demonstrated
- Test vessel for large footprint cells was designed and ordered